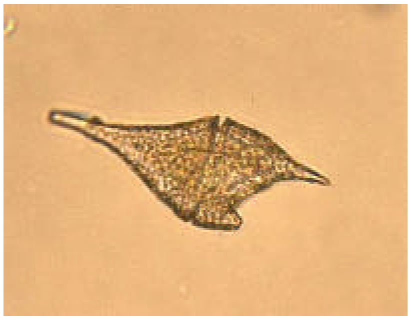
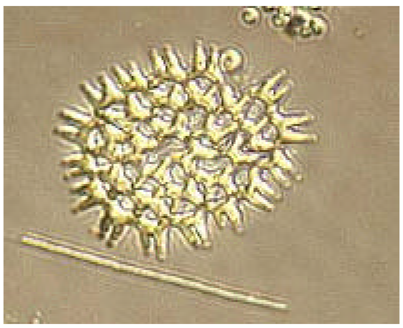
Phytoplankton Assemblage Composition and Abundance - Oologah Lake, Oklahoma, 24 April 2000 through 23 October 2001






Addendum to:
Oologah Lake Oklahoma Watershed Study
Year 2
Interim Report of Findings: October 2000 - September 2001

US Army Corps of Engineers
Southwestern Division
Tulsa District
Planning, Environmental, and Regulatory Division

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Executive Summary

This report provides a summary of data and findings obtained by the U.S. Army Corps of Engineers (USACE), Tulsa District (TD) for the Oologah Lake, Oklahoma, Watershed Study. This phase of investigation was conducted under the USACE Planning Assistance to States (PAS) Program. The project sponsor was the Oklahoma Water Resources Board (OWRB) with participation by the Tulsa Municipal Utilities Authority (TMUA). Results of previous investigations for the initial year of study (April through September 2000) were documented in an earlier TD report (USACE 2001). In an effort to maintain project continuity, this report includes presentation and analysis of data collected during the period October 2000 through October 2001.

A significant portion of this report is devoted not only to presentation of additional biological data collected during the study period, but also to comparison of these findings to data collected during the initial year of study. Major findings and conclusions pertaining to the biological (phytoplankton only) component of the study are provided below.

An example of the highly variable nature of the phytoplankton assemblage in Oologah Lake was the replacement of the Chlorophyta (green algae) by the Pyrrophyta (dinoflagellates) as a major assemblage component in the second year study (April through September 2001) relative to the first year study (April through September 2001) (Figure 7). The green algae present during year one of this study consisted primarily of the genus *Chlamydomonas* (Chlorophyta:Vovolcales) and comprised 28.2% of the total number of phytoplankton present. In the second year study, the *Chlamydomonas* comprised only 0.24% of the total number of phytoplankton encountered. The dinoflagellates, which replaced the green algae component of the assemblage in the second year, consisted primarily of the genus *Chroomonas* (Pyrrophyta:Cryptomondales) and comprised 33.9% of the total number of phytoplankton encountered.

During the second year study, sampling sites exhibiting the greatest degree of temporal variability in richness, evenness, and diversity included Site 1 and Site 2. Sites 3, 4, 5 did exhibit some variability in index scores; however, at those sites index scores remained fairly stable relative to Sites 1 and 2, especially with respect to taxa richness

(Figures 21 through 25). The patterns in index score variability mirror closely that of the Bray-Curtis similarity results across all sampling dates where Site 1 and Site 2 were identified as the more similar to each other than to the other sampling sites in the reservoir.

As was the evident in the first year study, the phytoplankton assemblage present in Oologah Lake is indicative of a eutrophic lake based on the general characteristics of common major algal associations (Wetzel 1983; Hutchinson 1967). According to the Wetzel (1983) classification, the algal assemblage characteristic of a eutrophic water body is dominated by diatoms a majority of the year and generally includes the genera *Asterionella*, *Fragilaria*, *Stephanodiscus*, *Melosira*, and *Syndra*. Of these, only *Asterionella* and *Fragilaria* were not present in the assemblage. Within the blue-green group Wetzel (1983) identifies the genera *Anacystis*, *Microcystis*, *Aphanizomenon*, and *Anabaena* to be the dominant components within eutrophic waters, all of which were found to be present at Oologah Lake throughout this study.

From a water supply stand point, the finding of the large contribution of the genus *Anabaena* (Cyanophyta:Hormongonales) to the total biovolume (a surrogate measure of biomass) of the assemblage present during this study is of particular importance. *Anabaena* is one of several genera of the blue-green algae known to produce geosmin and 2-methylisoborneol (MIB) (Tabachek and Yurkowski 1976), both which can impart an earthy or musty smell to water. Temporal changes observed in both blue-green algal densities and biovolume mirror the temporal variability observe in geosmin concentrations present in raw water from Oologah Lake (Figures 8, 27, and 28). Fortunately the genus *Anabaena* is the only genus know to contribute to taste-and-odor problems contributing significantly (< 1%) to the assemblage at present, however genera known to be responsible for taste-and-odor as well as aesthetic degradation (*Oscillatoria* and *Aphanizomenon*) are present in Oologah Lake.

Recommendations for further study include continued limnological (chemical, physical, and biological) data collection at Oologah Lake. Based on a review of phytoplankton data collected as a result of this study, it is likely that continued sampling would help clarify the influence of seasonal trends of autochthonous and allochthonous nutrient loading as well as physical factors (e.g. light attenuation and turbidity) on, what at this time, appears to be a highly variable and dynamic algal assemblage. It is also recommended that modeling efforts for the reservoir continue. Lake modeling would include further calibration of the CE-QUAL-W2 water quality model to include an algal/phytoplankton component to increase predictive capabilities.

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Introduction

This document provides a summary of phytoplankton data and findings obtained during fiscal year (FY) 2001 for the Oologah Lake, Oklahoma Watershed Study. Overall, the project is designed as a multi-year investigation aimed at evaluating ecosystem degradation and resulting water quality threats in the Verdigris River Basin, Oklahoma and Kansas. A key component of the investigation is Oologah Lake, Oklahoma, a significant ecological resources and important water supply source for the city of Tulsa, Oklahoma, as well as a number of communities surrounding the lake. Field sampling and data collection for the project were initiated by the U.S. Army Corps of Engineers, Tulsa District (TD) from April 2000 through November 2001. Study activities for the initial year of study were conducted under Congressional appropriation and confined to Oologah Lake itself and major tributary sites immediately adjacent to the reservoir. Data summaries and findings from this initial year were documented in an interim report prepared by the TD (USACE 2001).

The purpose of this report is to present phytoplankton data and findings from a second phase of investigations in the Verdigris River Watershed conducted under the Corps' Planning Assistance to States Program (PAS) Program (USACE 2002). The project sponsor was the Oklahoma Water Resources Board (OWRB) with participation by the Tulsa Municipal Utilities Authority (TMUA), Tulsa, Oklahoma. In an effort to maintain project continuity, the report includes presentation and analysis of data collected during the period October 2000 through October 2001; however, a major emphasis of the data presentation and analysis will focus on the April 2001 through September 2001 period for ease of comparison to the first year study (USACE 2001).

Methods and Materials

The methods used in the collection and preservation of phytoplankton, as well as the collection and analytical methods for water quality parameters, are presented in the year one interim report generated from this study (USACE 2001). At the time of analysis, phytoplankton samples were shaken vigorously and poured into 250 ml graduated cylinders. A drop of liquid soap was added and mixed in to break the surface tension. Cylinders were covered with Parafilm® and allowed to sit for at least one week and periodically tapped to dislodge cells from the cylinder walls during this period. After settling, the volume of the sample was recorded and the upper portion of the liquid was removed through use of a vacuum pump, reducing the sample volume to <15 ml. The sample was then transferred to a 25 ml graduated cylinder. The original 250 ml cylinder was rinsed 2 times with de-ionized water and added to the sample in the 25 ml cylinder. The sample volume was brought to 15 ml with de-ionized water and 2-3 drops of Lugol's solution are added for preservation and dyeing.

After settling, one milliliter of sample was placed in a Sedgwick-Rafter counting chamber and overlain with a coverslip. Samples were allowed to sit for approximately 15 minutes to allow for settling. Samples were viewed at 400x using a Nikon Model E600 compound microscope under phase contrast illumination. The objective is a 40x extended working distance phase objective, which allows for use of the counting chamber. Organisms were identified and enumerated as encountered. Dense samples were counted in fields while less sparse samples were counted in strips. Organisms were counted until at least one hundred individual cells/colonies had been identified; however, for almost all samples several hundred organisms were identified and counted. Colonial or filamentous organisms were counted as one organism. All organisms, with the exception of diatoms, were identified to at least the genus level; however, when organisms could easily be identified to the species level, or when an organism was dominant, further identification was undertaken. Very small organisms, especially minute flagellates which are common in plankton samples, were usually not identified, although they were enumerated.

Cell biovolume was estimated using a digital camera (Nikon Model DMX1200) linked to a PC with MetaView software. MetaView calculates volume by estimating the size of the selected organism if that organism was compressed to a sphere, a prolate, or an oblate shape. To calculate a cell volume, the organism is first identified and then a digital image is made with the camera. The outline of the organism is traced electronically using the mouse. The outlined image is then "thresholded" which is a process of establishing the optical density of the shape to be measured. Given that the whole traced image is to be measured, the entire image is colored using the threshold function. After this step, the appropriate magnification is entered into the program and the desired measurements are selected (length, width, volume, etc.). Each of these measurements is recorded for each organism measured and the two closest measurements are averaged, unless all three are similar. A minimum of 10 organisms are measured for each taxon if encountered, unless there is considerable variation. For some taxa, volumes can be directly measured (e.g. filamentous diatoms) using length and width. Robert Lynch, University of Oklahoma, Health Sciences Center, performed all phytoplankton identification, enumeration, and biovolume calculations.

Statistical analyses were conducted using MINITAB 13 (Minitab, Inc. 2000). For hypothesis testing, differences were considered statistically significant $\alpha \leq 0.10$ in an attempt to better account for ecological rather than statistical trends. Analyses were first performed to determine if the data deviated significantly from that of a normal distribution using the Anderson-Darling normality test. Once a normal or lognormal distribution was determined, analyses were performed to determine differences between sampling sites both spatially and temporally using tests appropriate for the distribution. Generally, differences among sampling sites and events were determined using analysis of variance (ANOVA) on ranked data. When differences among the medians were detected, Tukey's multiple comparison test was utilized to determine which medians were different.

Results

Taxa Enumeration. The phytoplankton assemblage in Oologah Lake between April 2000 and October 2001 was represented by 57 genera within 12 orders and 5 divisions. Depending upon the taxonomic level under evaluation, groups of unidentified microflagellates, unspecified Pyrrophyta (dinoflagellates), and Pennales (diatoms) were also included in the count data. Table 1 list the phytoplankton taxa identified in Oologah Lake between April 2000 and October 2001. Of the 57 genera identified in samples from Oologah Lake collected between April 2000 and October 2001, 24.5% (14/57) belonged to the division Cyanophyta (blue-greens), 14.0% (8/57) belonged to the division Bacillariophyta (diatoms), 43.8% (25/57) belonged to the division Chlorophyta (green algae), 7.0% (4/57) belonged to the division Euglenophyta (euglenoids), and 8.8% (5/57) belonged to the division Pyrrophyta (dinoflagellates).

Based upon total counts of organisms, the diatoms and dinoflagellates dominated the algal assemblage in Oologah Lake during the 19 month study period (Figure 1) and contribution to the assemblage was equitably split between these two groups. The blue-greens, green algae, euglenoids, and microflagellates together comprised 37.1% of the phytoplankton assemblage. Of the 12 orders identified, 73.0% of the species abundance was contributed by only three, the Centrales (Bacillariophyta), the Cryptomonadales (Pyrrophyta), and the Volvocales (Chlorophyta) (Figure 2). Within the Centrales, the most abundant genera included *Stephanodiscus* and *Aulacoseria* comprising 16.0% and 14.7% of the assemblage respectively. Within the Cryptomonadales, the most abundant genera included *Chroomonas* and *Cryptomonas* which comprised 21.9% and 6.1% of the assemblage, respectively. Figure 3 presents the percent contribution to the assemblage of the genera contributing greater than 1% to the overall assemblage.

For comparison with the results of the year one study (USACE 2001), the phytoplankton counts from samples collected between April and September 2001 were subset and analyzed separately. The most dramatic shift in the phytoplankton assemblage between the two study periods (April through September 2000 and April through September 2001) was the absence of the Chlorophyta as a major component of the assemblage in 2001. Between April and September 2000, the Chlorophyta comprised

41.2% of the assemblage; however, between April and September 2001, the Pyrrophyta had replaced the Chlorophyta as the dominant division and comprised 41.0% of the assemblage. Between both study periods, the contribution to the phytoplankton assemblage by the Bacillariophyta remained comparatively stable. A comparison of the percent contribution for each division during both study periods is presented in Figure 4. During the April through September 2001 period, 45 genera within 11 orders were identified. The order Gynmnodinales (a dinoflagellate), present in 2000, represented only 0.08% of the assemblage in 2000 with only one representative genus, *Gymnodinium*, was not present during the April through September 2001 study period.

Of the 11 orders present during the second year study only three orders as well as the group identified as unspecified microflagellates represented 88.0% of the overall phytoplankton assemblage. Theses included the Cryptomonadales (40.8%), the Centrales (29.4%), the unspecified microflagellates (11.1%), and the Chroococcales (6.8%) (Figure 5). Within the order Cryptomonadales the genus *Chroomonas* comprised 33.9% of the overall assemblage and the genus *Cryptomonas* comprised 6.8%. Genera representative of the order Centrales include the genus *Stephanodiscus* and the genus *Aulacoseira* which comprised 19.8% and 9.5% of the assemblage respectively. Within the order Chroococcales only one genus exhibited an abundance greater than one percent, the genus *Merismopedia* which comprised 1.6% of the assemblage. Figure 6 presents the percent contribution of genera with a contribution greater than 1%. The category of other is made up of the 37 genera which comprised less that 1% of the overall phytoplankton assemblage.

Spatially, the phytoplankton assemblage was significantly different across all sampling sites and sampling dates (one-way ANOVA on ranked count data, $F = 4.83$, $p = 0.001$) with sampling sites separated into two groups, Site 1 $\leq$ Site 2 = Site 3 = Site 4 $\neq$ Site 5. Temporally, it was observed that, based on total count data, the median total count was significantly greater across all sampling sites and dates during the second year study ($F = 4.\ 24$, $p = 0.014$). Although there was a statistical difference in total count between the two study years, trends indicate that the relative frequency of each division were similar at each sampling site between the two study periods with the exception of the Pyrrophyta. At each sampling site across all sampling dates, the Pyrrophyta replaced the Chlorophyta in terms of total contribution to the assemblage (Figure 7). Temporally, at the division level the phytoplankton assemblage was quite variable. Figures 8 through 10 present the total counts of each division on each sampling date from April 2000 through September 2001 for Sites 1 through 3. Trend analysis indicates that, at the division level, only the Chlorophyta appear to be correlated with chlorophyll *a* concentrations with the total number of Chlorophyta present corresponding with peaks in chlorophyll *a* concentration at each site.

<u>Similarity and Diversity</u>. The Bray-Curtis similarity index was used to assess station similarity at the taxonomic level of genus across all sampling dates and on each sampling date. As shown in Figure 11, across all sampling dates, Site 1 was determined to be 53.5% dissimilar from all other sampling sites. Furthermore, Sites 2, 4, and 5 were found to be 31.6% dissimilar from Site 3, Site 2 25.8% dissimilar from Sites 4 and 5, and Sites 4 and 5 14.3% dissimilar from each other in taxonomic composition. In general, the similarity index determined Site 1 to be greater than 78% dissimilar to the other sampling sites (i.e. only 22% similar to all other sampling sites) on 33% (3 of 9) of the sampling dates and the taxonomic composition was found to be similar to that of Site 4 and Site 5 on only one date, 15 May 2001. On 66.7% of the sampling dates (4 of 9) Site 2 and Site 3 were found to be similar in taxonomic composition with the degree of dissimilarity ranging from 0.06% on 29 May 2001 to 41.4% on 24 April 2001. Instances where Site 1 intersected directly with the Site 2 and Site 3 node occurred on four dates. In three of those four instances the degree of dissimilarity between Sites 1, 2, and 3 ranged from 59.9% to 78.3%. On 29 May 2001, Sites 4 and 5 were not sampled due to inclement weather, however it can be reasonably inferred that the taxonomic composition of the lower lake was likely distinct from that of the upper lake on that date. Sites 4 and 5 were grouped together by the same node on 55.6% (5 of 9) sampling dates. On those dates, the degree of taxonomic dissimilarity ranged from 23.9% to 40.7%. Figures 12 through 20 present the Bray-Curtis dissimilarity dendrograms for individual sampling dates.

Species diversity and evenness were calculated using Brillouin's Diversity Index (log 10 base). Across all sampling dates, Site 5 exhibited the greatest species diversity and evenness with a diversity index score of 1.042, an evenness score of 0.692, and a richness of 32 genera present. Site 1 exhibited the lowest species diversity, evenness, and richness with index scores of 0.555, 0.363, and 34 respectively. Index scores for diversity, evenness, and richness are presented in Table 2. Figures 21 through 25 provide Brillouin's diversity, evenness, and richness each sampling site throughout the study period of April through September 2001.

Bio-volume. Another method available to characterize the contribution various components make to the overall phytoplankton assemblage is the measurement of biovolume. Biovolume measurements of phytoplankton taxa present in Oologah Lake were made for all samples collected from 24 October 2000 through 23 October 2001. As with count (enumeration) data, there are several ways biovolume data can be presented. The results presented here, as is the case for the count data, represent a first order analysis in an attempt to describe the general composition of the phytoplankton assemblage. Based upon biovolume, the Bacillariophyta (diatoms) and Cyanophyta (blue-greens) tended to dominate the assemblage between October 2000 and October 2001 with the diatoms contributing 51% and the blue-greens contributing 30% of the assemblage, by volume (Figure 26). The contribution of the Pyrrophyta (dinoflagellates) and the Chlorophyta (green algae) was equitably split with each contributing 7% and 9% respectively. The Euglenophyta (euglenoids) and the group identified as unspecified flagellates represented only minor contributions.

At the taxonomic level of Order, the Centrales (Bacillariophyta) was the dominant group comprising a little more than half the biovolume of the assemblage (50.4%). The second most abundant group, by volume, was the Hormogonales (Cyanophyta) (29.4%). The remaining nine orders comprised, by volume, 19.5% of the assemblage with two groups, unspecified flagellates and unspecified Pyrrophyta (also flagellated) comprising 0.7% of the assemblage collectively (Table 3). At the genus level, the genera which comprised less than 1% of the assemblage were consolidated into a general group labeled as other. Nine genera and a general group of unspecified flagellates each comprised greater than 1% of the assemblage. The dominant genera included *Aulacoseria* (Bacillariophyta:Centrales) and *Anabaena* (Cyanophyta:Hormogonales) which represented 44.5% and 30.9% of the assemblage, respectively. Genera representing greater than 1% of the assemblage, by volume, are presented in Table 4.

Across all sampling dates biovolume was significantly different among sampling stations and three general groups were identified (Table 5). Analysis on individual sampling dates found that a significant differences in biovolume among stations occurred on only two dates, 6/19/01 and 8/21/01 (Table 5), otherwise no significant difference in total assemblage biovolume was identified among sampling sites on individual sampling dates. In addition, there was a significant correlation (Spearman rank correlation) across all sampling dates between chlorophyll *a* and biovolume of the Bacillariophyta ($r = 0.720$, $p < 0.001$), Cyanophyta ($r = 0.435$, $p = 0.001$), Euglenophyta ($r = 0.431$, $p = 0.001$), Pyrrophyta ($r = 0.359$, $p = 0.005$), and unspecified flagellates ($r = 0.509$, $p < 0.001$). No significant correlation was found between chlorophyll *a* and the Chlorophyta biovolume.

The temporal dynamics exhibited by the phytoplankton assemblage in Oologah Lake are of primary importance at the near dam sampling site, Site 1, due to its proximity to the City of Tulsa's water supply intake structure. As was observed throughout the lake, the dominant phytoplankton throughout much of the October 2000 through October 2001 sampling period at Site 1 was the Bacillariophyta (diatoms). Examination of the temporal trends at Site 1 indicate that the Divisions likely responsible for the greatest contribution to chlorophyll *a* concentrations include the Bacillariophyta and the Chlorophyta (Figure 27). Additional trend analysis indicates, not unexpectedly, geosmin concentrations sampled at the outlet of the 66" water line from the Oologah Lake intake into A.B. Jewel reservoir mirror trends observed in chlorophyll *a* concentrations at Site 1 (Figure 28).

Discussion

In general the seasonal pattern in phytoplankton abundance follows a predictable pattern of bloom and senescence. In temperate lakes, that pattern usually consists of spring and fall blooms with each bloom followed by summer and winter declines in abundance (Hutchinson 1967; Goldman and Horne 1983). Standing crop count data from Oologah Lake collected throughout this study (April 2000 through October 2001) indicates that the phytoplankton assemblage exhibits seasonal variability (Figures 8, 9, and 10) throughout the spring, summer, and fall months. Changes in the composition of the phytoplankton assemblage can be related to the inter- and intra-annual variability in physical factors such as hydraulic residence time, Secchi depth, rainfall, and turbidity (LaBaugh 1995).

The most dramatic example of the highly variable nature of the phytoplankton assemblage standing crop in Oologah Lake is the replacement of the Chlorophyta (green algae) by the Pyrrophyta (dinoflagellates) as a major assemblage component in the second year study (April through September 2001) relative to the first year study (April through September 2001) (Figure 7). The green algae present during year one of this study consisted primarily of the genus *Chlamydomonas* (Chlorophyta:Vovolcales) and comprised 28.2% of the total number of phytoplankton present. In the second year study, the *Chlamydomonas* comprised only 0.24% of the total number of phytoplankton encountered. The dinoflagellates, which replaced the green algae component of the assemblage in the second year, consisted primarily of the genus *Chroomonas* (Pyrrophyta:Cryptomondales) and comprised 33.9% of the total number of phytoplankton encountered.

During the second year study sampling sites exhibiting the greatest degree of temporal variability in richness, evenness, and diversity included Site1 and Site 2. Sites 3, 4, 5 did exhibit some variability in index scores; however, at those sites index scores remained fairly stable relative to Sites 1 and 2, especially with respect to taxa richness (Figures 21 through 25). The patterns in index score variability mirror closely that of the Bray-Curtis similarity results across all sampling dates where Site 1 and Site 2 were identified as the more similar to each other than to the other sampling sites in the reservoir.

A second analytical approach incorporated into the analysis of biological samples for the second year study included the measurement of standing crop biovolume. Studies which incorporate the measurement of both chlorophyll *a* and biovolume are rare (LaBaugh 1995), but the inclusion of both allows for a more realistic approximation of standing crop biomass as well as the ability to examine chlorophyll *a* to algal biovolume ratios within and across all taxa groups. Biovolume results for the second year study indicate that the assemblage was dominated by two groups volumetrically: the Bacillariophyta (diatoms) (51%) and the Cyanophyta (blue-greens) (30%). The remaining Divisions included the Chlorophyta (green algae), the Pyrrophyta (dinoflagellates), the Euglenophyta (euglenoids), and a general group of unspecified flagellates which together comprised 19% of the assemblage. The dominant genera, by volume, in the second year study included the genus *Aulacoseria* (Bacillariophyta:Centrales) and the genus *Anabaena* (Cyanophyta:Hormogonales) and comprised 44.5% and 30.9% of the total biovolume of the assemblage, respectively. When using count data only, the genus *Anabaena* comprised only 3.3% of the assemblage while the genus *Aulacoseria* comprised 11.7% (Table 4).

As was the evident in the first year study, the phytoplankton assemblage present in Oologah Lake is indicative of a eutrophic lake based on the general characteristics of common major algal associations (Wetzel 1983; Hutchinson 1967). According to the Wetzel (1983) classification, the algal assemblage characteristic of a eutrophic water body is dominated by diatoms a majority of the year and generally includes the genera *Asterionella*, *Fragilaria*, *Stephanodiscus*, *Melosira*, and *Syndra* of which only *Asterionella* and *Fragilaria* were not present in the assemblage. Of the diatom genera present throughout this study, only the genus *Stephanodiscus* was found to comprise greater than 10% of the assemblage by density and comprised 7.8% of the assemblage by volume. Other components commonly found to be present in eutrophic waters include blue-green algae and euglenoids. Within the blue-green group Wetzel (1983) identifies the genera *Anacystis*, *Microcystis*, *Aphanizomenon*, and *Anabaena* to be the dominant components within eutrophic waters, all of which were found to be present throughout this study. Of these blue-green genera, *Anacystis* and *Anabaena* were present in densities greater than 1% of the phytoplankton assemblage. Surprisingly, while the genus

Anabaena comprised less than 5% of the assemblage based upon algal densities alone, this genus comprised 30.9% of the assemblage by volume. Euglenoids, generally considered to be indicative of polluted or organically enriched waters (Wetzel 1983) were present at densities and volumes that comprised less than 1% of the assemblage indicating that organic enrichment and pollution may not be of major concern within Oologah Lake at this time.

From a water supply standpoint, the finding of the large contribution of the genus *Anabaena* (Cyanophyta:Hormongonales) to the total biovolume (a surrogate measure of biomass) of the assemblage present during this study is of particular importance. *Anabaena* is one of several genera of the blue-green algae known to produce geosmin and 2-methylisoborneol (MIB) (Tabachek and Yurkowski 1976), both which can impart an earthy or musty smell to water. Temporal changes observed in both blue-green algal densities and biovolume mirror the temporal variability observed in geosmin concentrations present in raw water from Oologah Lake (Figures 8, 27, and 28). Fortunately the genus *Anabaena* is the only genus know to contribute to taste-and-odor problems contributing significantly (< 1%) to the assemblage at present, however genera known to be responsible for taste-and-odor as well as aesthetic degradation (*Oscillatoria* and *Aphanizomenon*) are present in Oologah Lake.

Recommendations for further study include continued limnological (chemical, physical, and biological) data collection at Oologah Lake. Based on a review of phytoplankton data collected as a result of this study, it is likely that continued sampling would help clarify the influence of season trends of autochthonous and allochthonous nutrient loading as well as physical factors (e.g. light attenuation and turbidity) on, what at this time, appears to be a highly variable and dynamic algal assemblage. It is also recommended that modeling efforts for the reservoir continue. Lake modeling would include further calibration of the CE-QUAL-W2 water quality model to include an algal/phytoplankton component to increase predictive capabilities.

Table 1. Phytoplankton taxa present during each study period (April through October).

Division	Order	Genus species	2000	2001
Bacillariophyta	Centrales	*Acanthoceros Zachariasii*		x
		Aulacoseira distans	x	x
		Aulacoseira granulata	x	x
		Chaetoceros sp.	x	
		Melosira varians	x	x
		Stephanodiscus spp.	x	x
	Pennales	*Asterionella formosa*	x	x
		Gyrosigma sp.	x	
		Synedra sp.	x	x
		Synedra ulna	x	x
Chlorophyta	Chlorococcales	*Actinastrum hantzschii*	x	x
		Actinastrum sp.	x	
		Ankistrodesmus falcatus	x	x
		Coelastrum sp.	x	x
		Crucigenia sp.	x	x
		Franceia sp.		x
		Gloeocystis (?) sp.	x	x
		Golenkinia sp.	x	x
		Kirchneriella sp.		x
		Lagerheimia sp.		x
		Micratinium pusillum	x	
		Nephrocytium sp.		x
		Oocystis (?) sp.	x	
		Oocystis sp.	x	x
		Oocystis spp.	x	
		Pediastrum duplex	x	x
		Pediastrum simplex		x
		Quadrigula lacustris	x	x
		Scenedesmus bijuga	x	
		Scenedesmus quadricauda	x	
		Scenedesmus sp.	x	x
		Schroederia setigera	x	x
		Selenastrum sp.	x	x
		Tetraedron sp.	x	x
		Tetrastrum sp.	x	x
		Treubaria sp.	x	x

Table 1 (continued). Phytoplankton taxa present during each study period (April through September).

Division	Order	Genus species	2000	2001
	Desmidiales	*Closterium* sp.	x	x
		Cosmarium sp.	x	x
		Cosmarium sp. (*dentatum*?)	x	
		Staurastrum sp.	x	x
	Volvocales	*Carteria* sp.	x	x
		Chlamydomonas sp.	x	
		Chlamydomonas spp.	x	x
Cyanophyta	Chroococcales	*Anacystis* sp.1	x	
		Anacystis sp.2	x	
		Anacystis sp.3	x	
		Anacystis spp.		x
		Aphanothece sp.	x	
		Chroococcus sp.	x	x
		Dactylococcopsis acicularis		x
		Dactylococcopsis fasciculata		x
		Dactylococcopsis smithii		x
		Dactylococcopsis sp.	x	x
		Gomphosphaeria sp.	x	x
		Merismopedia elegans(?)		x
		Merismopedia glauca	x	x
		Merismopedia sp.	x	
		Merismopedia tenuissima	x	x
		Microcystis(?) sp.	x	x
		Pelogloea bacillifera	x	
		Raphidiopsis(?) sp.	x	
	Hormogonales	*Anabaena circinalis*	x	x
		Anabaena sp.	x	x
		Aphanizomenon sp.	x	x
		Lyngbya sp.		x
		Lyngbya spp.		
		Oscillatoria sp.	x	x
		Spirulina sp.		x
Euglenophyta	Euglenales	*Euglena* sp.	x	x
		Euglena spp.	x	x
		Lepocinclis sp.	x	x
		Phacus (?)sp.	x	x
		Phacus sp.	x	x

Table 1 (continued). Phytoplankton taxa present during each study period (April through September).

Division	Order	Genus species	2000	2001
Euglenophyta	Euglenales	*Trachelomonas* sp.	x	x
		Trachelomonas spp.	x	x
Pyrrophyta	Ceratiales	Ceratium cornutum	x	
		Ceratium hirundinella	x	x
	Cryptomonadales	Chroomonas Norstedtii		x
		Cryptomonas ovata	x	x
		Cryptomonas sp.	x	x
		Cryptomonas sp. (aspera?)	x	x
	Gymnodinales	Gymnodinium sp.	x	
		Gymnodinium(?) sp.	x	
	Peridinales	Peridinium sp.	x	x

Table 2. Brillouin's diversity, evenness, and richness at the genus level across all sampling dates from April through September 2001.

Site	Diversity Index	Evenness	Richness
1	0.555	0.363	34
2	0.836	0.533	37
3	0.891	0.568	37
4	0.971	0.634	34
5	1.042	0.692	32

Table 3. Percent contribution of each order to the phytoplankton assemblage in both density and biovolume from October 2000 through October 2001.

Order	Enumeration	Biovolume
Centrales	30.9	50.4
Ceratiales	0.1	3.6
Chlorococcales	2.7	7.0
Chroococcales	6.2	1.1
Cryptomonadales	39.3	3.3
Desmidiales	0.04	1.2
Euglenales	1.9	1.9
Hormogonales	3.7	29.4
Pennales	3.2	0.5
Peridinales	0.1	0.2
Volvocales	2.0	0.7
unspecified flagellate	9.7	0.6
unspecified Pyrrophyta	0.04	0.1

Table 4. Percent contribution of each genera to the phytoplankton assemblage in both density and biovolume from October 2000 through October 2001.

Genus	Enumeration	Genus	Biovolume
Chroomonas	31.6	*Aulacoseira*	39.5
Stephanodiscus	17.7	*Anabaena*	27.4
Aulacoseira	11.7	*Stephanodiscus*	7.8
unspecified flagellate	9.3	*Pediastrum*	4.2
Cryptomonas	5.9	*Ceratium*	3.4
Anacystis	4.2	*Cryptomonas*	1.6
Anabaena	3.3	*Chroomonas*	1.5
Carteria	1.6	*Ankistrodesmus*	1.2
Merismopedia	1.3	unspecified flagellate	1.1
Euglena	1.0	*Staurastrum*	1.0
Oocystis	0.8	*Trachelomonas*	0.8
Trachelomonas	0.7	*Euglena*	0.8
Schroederia	0.7	*Anacystis*	0.6
Scenedesmus	0.4	*Carteria*	0.6
Chlamydomonas	0.3	*Oocystis*	0.6
Dactylococcopsis	0.2	*Merismopedia*	0.3
Ankistrodesmus	0.2	*Acanthoceros*	0.3
Chroococcus	0.1	*Oscillatoria*	0.3
Phacus	0.1	*Coelastrum*	0.2
Coelastrum	0.1	*Peridinium*	0.2
Oscillatoria	0.1	*Scenedesmus*	0.2
Crucigenia	0.1	*Phacus*	0.2
Pediastrum	0.1	*Schroederia*	0.2
Acanthoceros	0.1	*Closterium*	0.1
Peridinium	0.1	*Treubaria*	0.1
Ceratium	0.1	*Microcystis*	0.1
Franceia	0.04	*Gloeocystis*	0.1
Quadrigula	0.04	*Melosira*	0.04
Gloeocystis	0.03	*Cosmarium*	0.03
Kirchneriella	0.03	*Aphanizomenon*	0.03
Microcystis	0.03	*Chlamydomonas*	0.03
Staurastrum	0.02	*Dactylococcopsis*	0.02
Treubaria	0.02	*Gomphosphaeria*	0.01
Aphanizomenon	0.02	*Spirulina*	0.01
Lyngbya	0.02	*Lepocinclis*	0.01
Spirulina	0.01	*Kirchneriella*	0.01
Lepocinclis	0.01	*Chroococcus*	0.01
Tetraedron	0.01	*Crucigenia*	0.01
Lagerheimia	0.01	*Franceia*	0.01
Selenastrum	0.01	*Lyngbya*	0.01
Cosmarium	0.01	*Quadrigula*	0.01

Table 4 (continued). Percent contribution of each genera to the phytoplankton assemblage in both total count and biovolume from October 2000 through October 2001.

Genus	Enumeration	Genus	Biovolume
Nephrocytium	0.01	*Nephrocytium*	0.01
Actinastrum	0.01	*Selenastrum*	0.002
Melosira	0.01	*Actinastrum*	0.002
Closterium	0.01	*Lagerheimia*	0.001
Golenkinia	0.003	*Tetraedron*	0.001
Gomphosphaeria	0.003	*Golenkinia*	0.0004

Table 5. Results of one-way ANOVA and Tukey's multiple comparison test performed on ranked biovolume data collected between October 2000 and October 2001. Letters identify statistically distinct groups.

Date	F	p	multiple comparision test	
all dates inclusive	8.67	< 0.001	1	A
			2	A B
			3	A B
			4	C B
			5	C
10/24/00		*		
11/28/00		*		
3/13/01		*		
4/24/01		*		
5/15/01		*		
5/29/01		*		
6/19/01	3.30	0.015	1	A
			2	B
			3	AB
			4	AB
			5	AB
7/17/01		*		
7/31/01		*		
8/21/01	4.94	0.001	1	A
			2	AB
			3	AB
			4	B
			5	B
9/4/01		*		
9/18/01		*		
10/23/01		*		

* = not significant

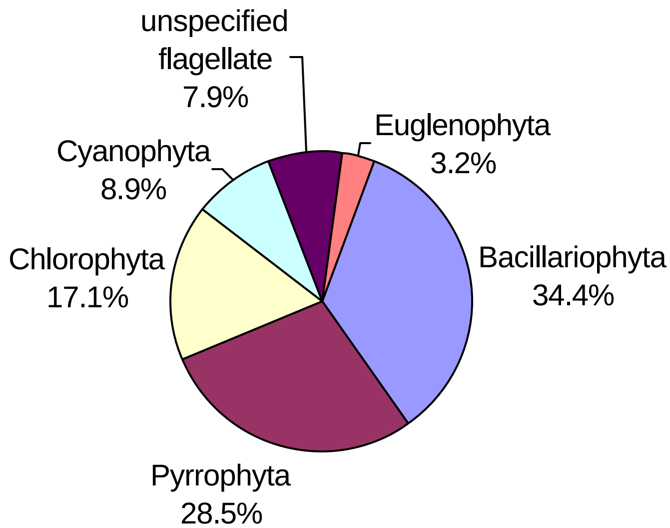


Figure 1. Percent contribution (density) of each division to the phytoplankton assemblage from April 2000 through October 2001.

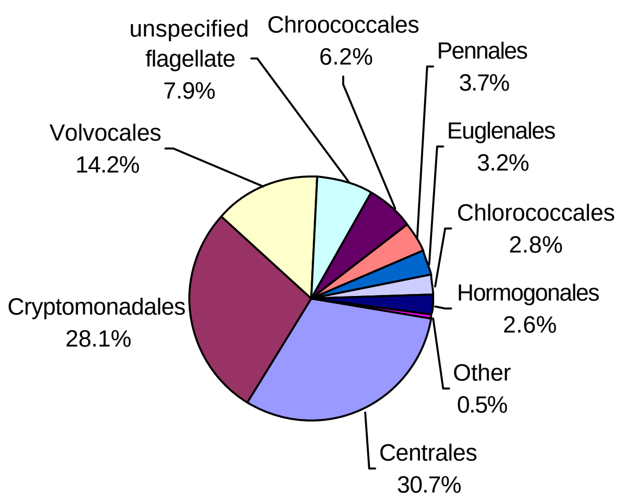


Figure 2. Percent contribution (density) of each order to the phytoplankton assemblage from April 2000 through October 2001.

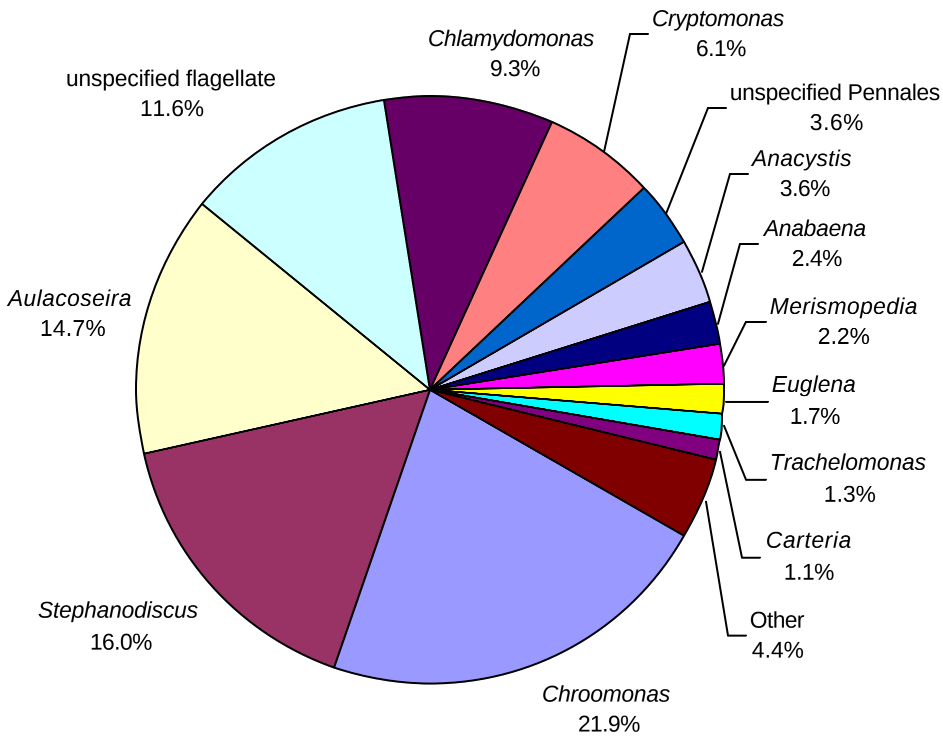
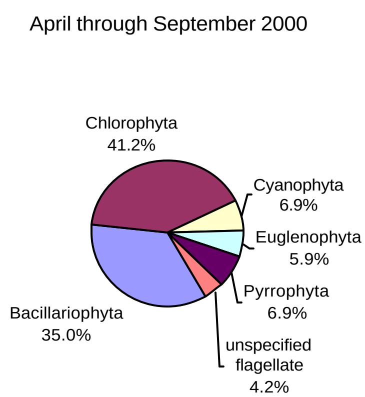


Figure 3. Percent contribution (density) of the most abundant genera encountered from April 2000 through October 2001.



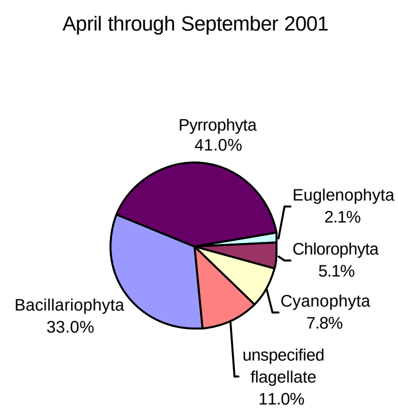


Figure 4. Percent contribution (density) of each division to the phytoplankton assemblage during both the Year 1 and Year 2 studies.

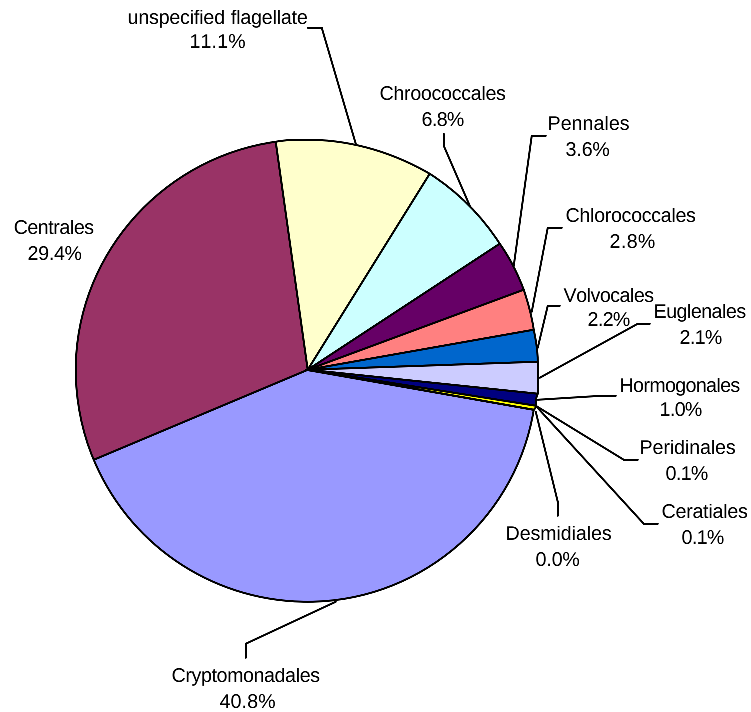


Figure 5. Percent contribution (density) of each order to the phytoplankton assemblage from April through September 2001.

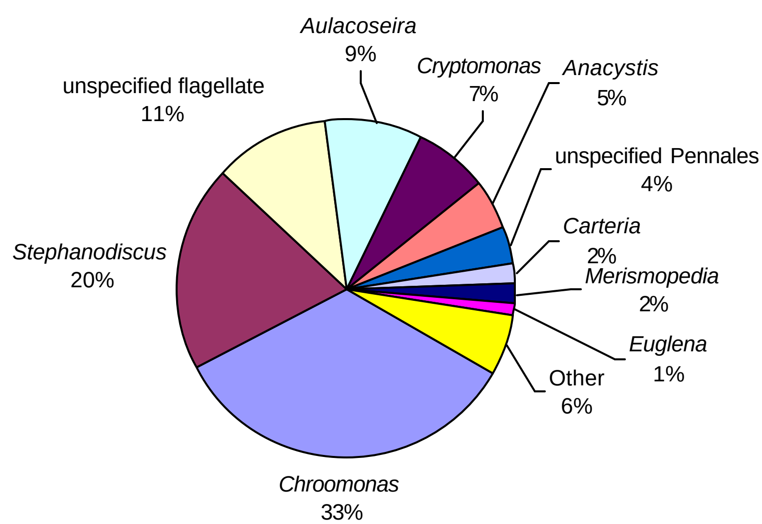


Figure 6. Percent contribution (density) of each genus to the phytoplankton assemblage from April through September 2001.

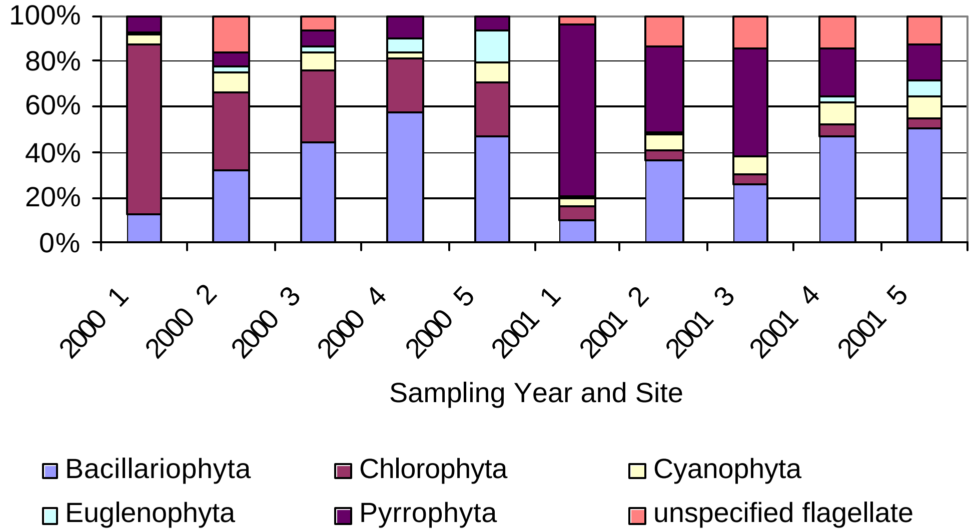


Figure 7. Percent contribution (density) at the division level at each sampling site across all sampling dates from April through September 2001.

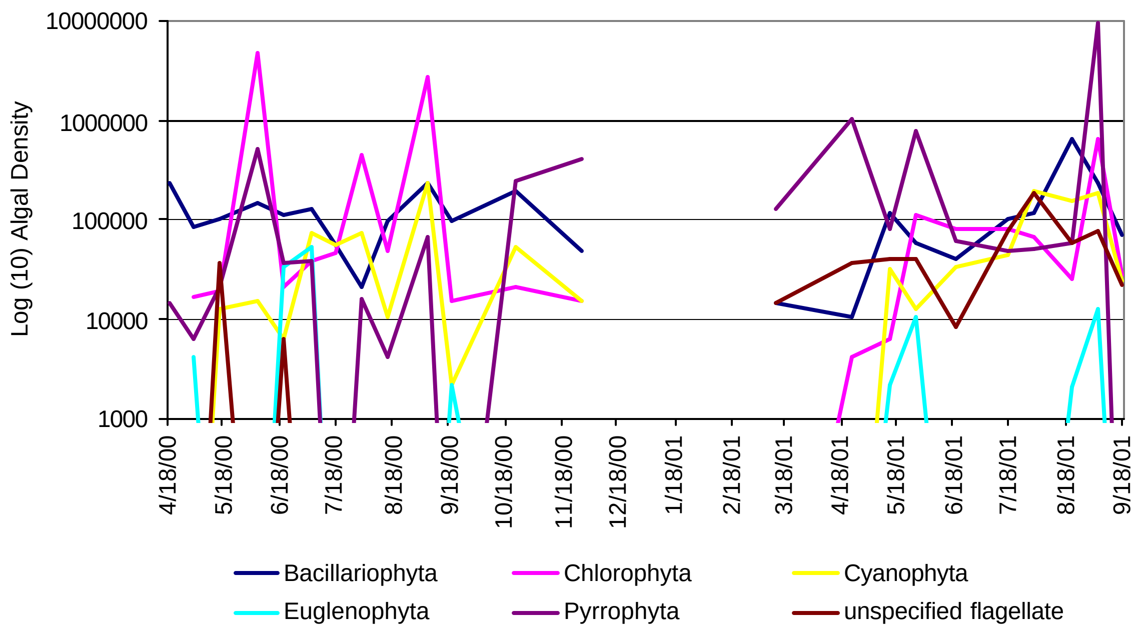


Figure 8. Algal densities at Site 1 on each sampling date.

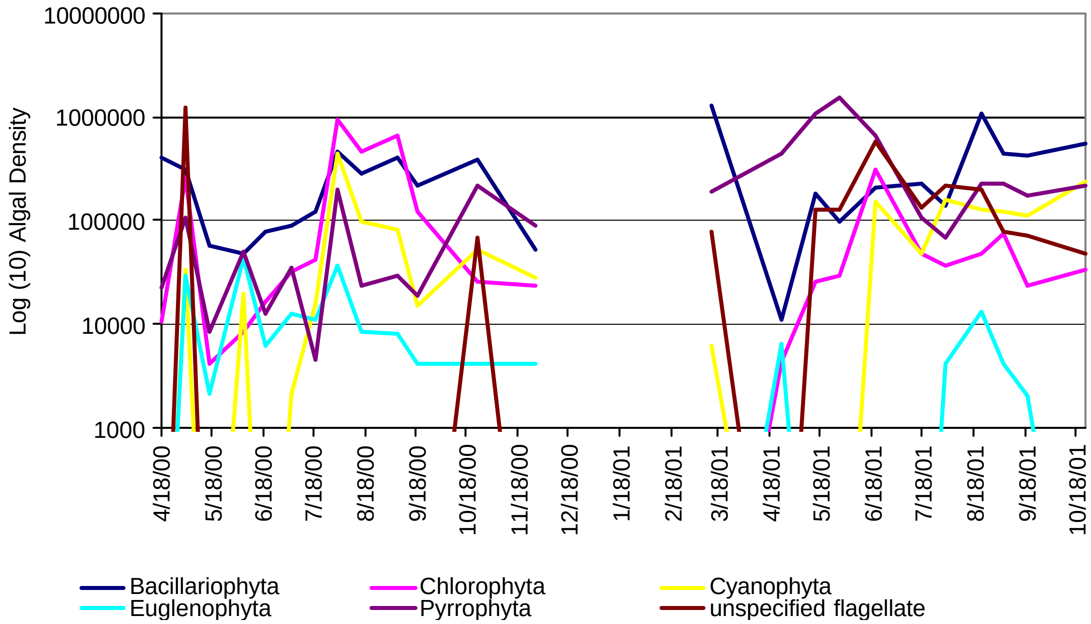


Figure 9. Algal densities at Site 2 on each sampling date.

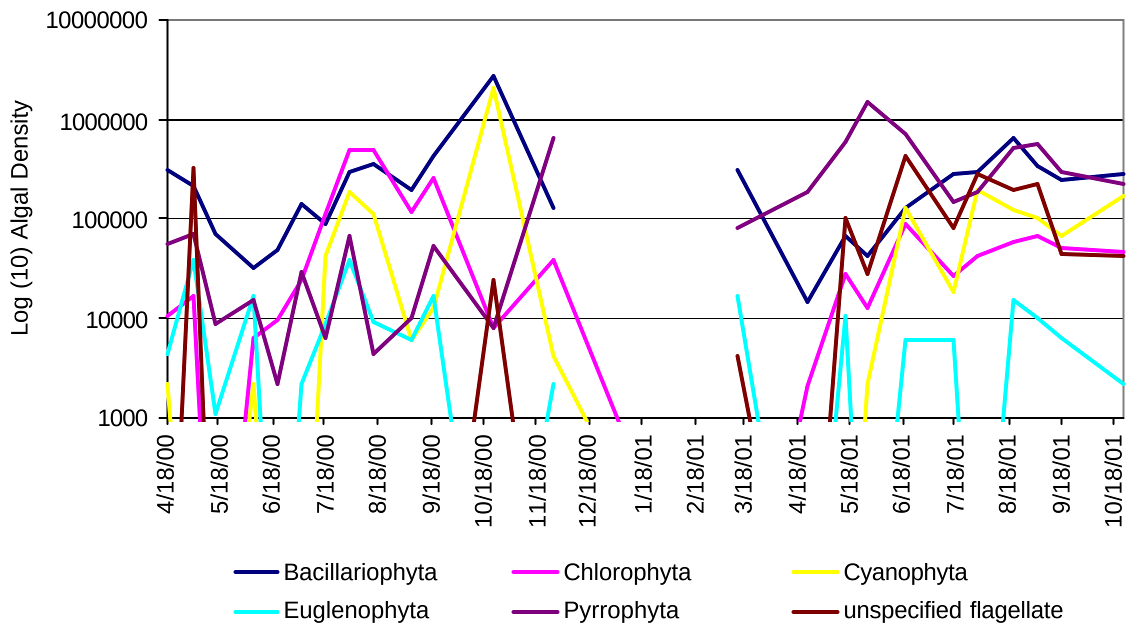


Figure 10. Algal densities as Site 3 on each sampling date.

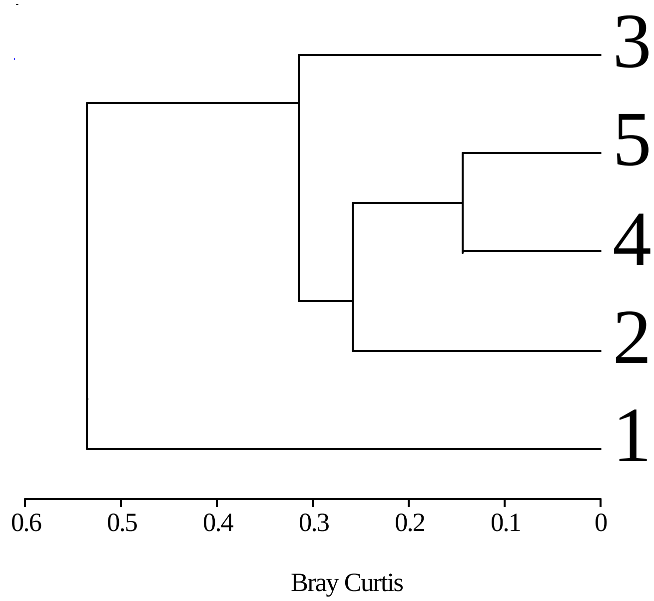


Figure 11. Bray-Curtis dissimilarity of sampling sites on April through September 2001.

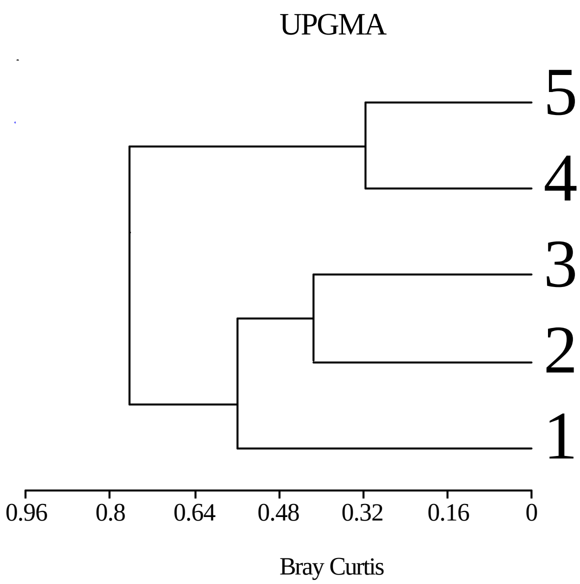


Figure 12. Bray-Curtis dissimilarity of sampling sites on 24 April 2001.

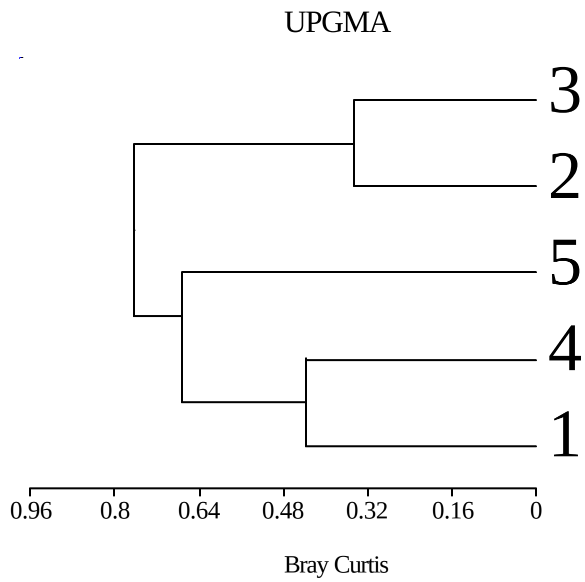


Figure 13. Genus Bray-Curtis dissimilarity of sampling sites on 15 May 2001.

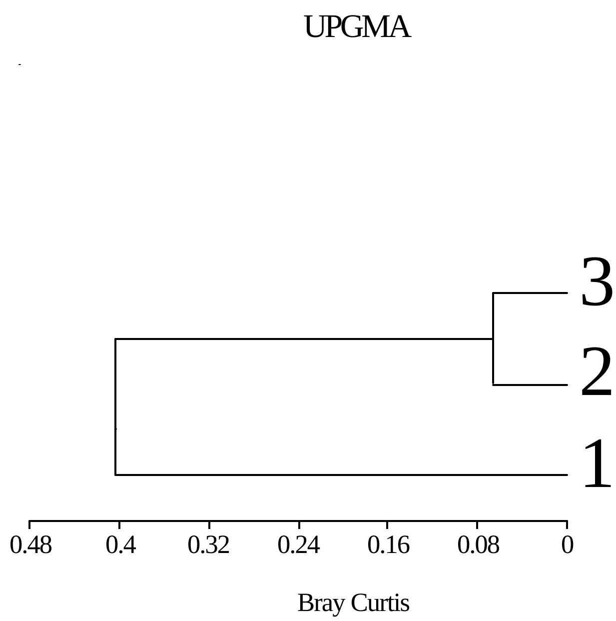


Figure 14. Genus Bray-Curtis dissimilarity of sampling sites on 29 May 2001.

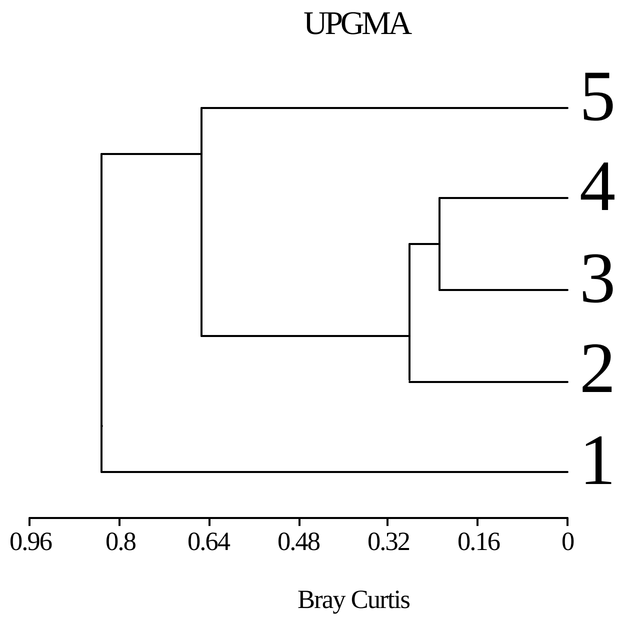


Figure 15. Genus Bray-Curtis dissimilarity of sampling sites on 19 June 2001.

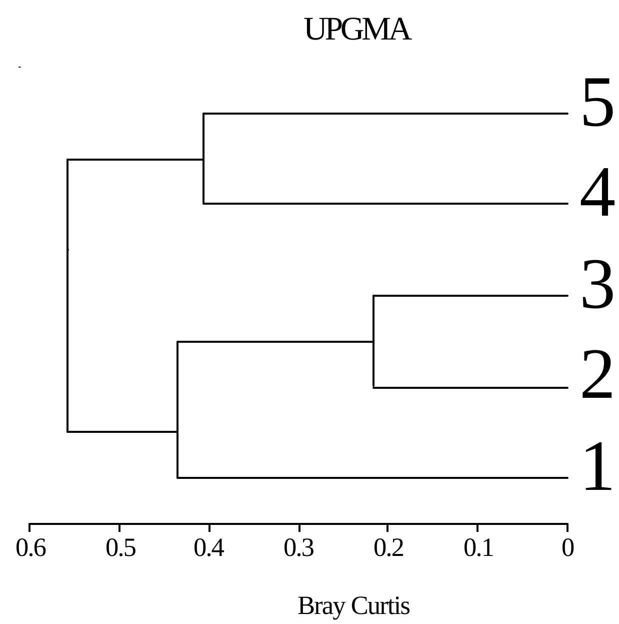


Figure 16. Genus Bray-Curtis dissimilarity of sampling sites on 17 July 2001.

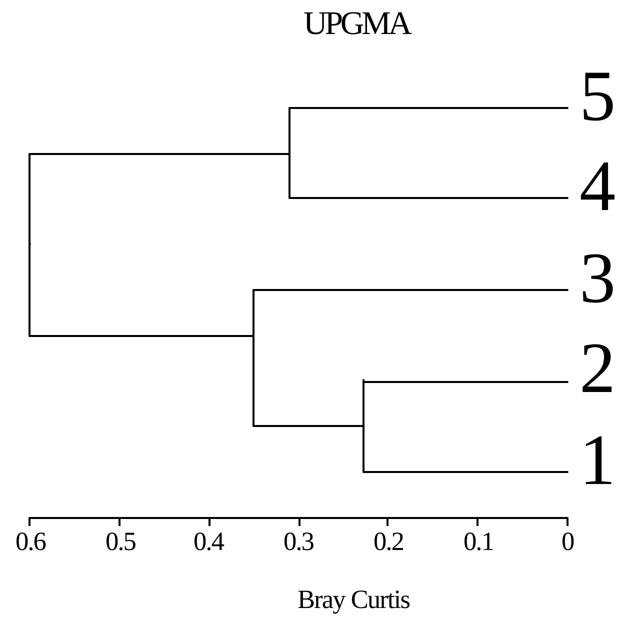


Figure 17. Genus Bray-Curtis dissimilarity of sampling sites on 31 July 2001.

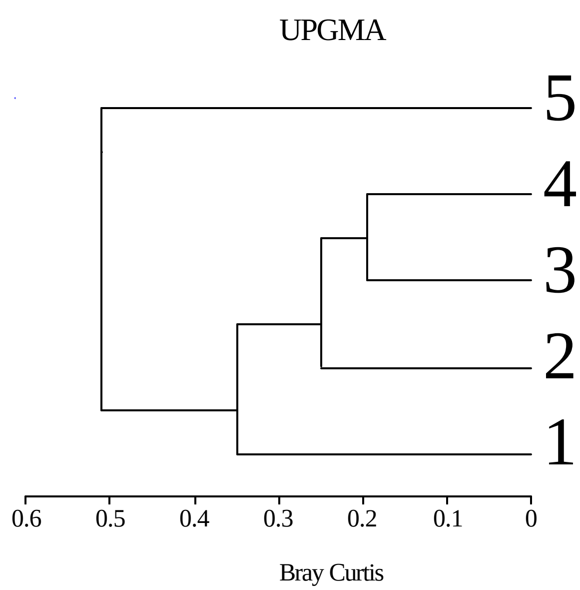


Figure 18. Genus Bray-Curtis dissimilarity of sampling sites on 21 August 2001.

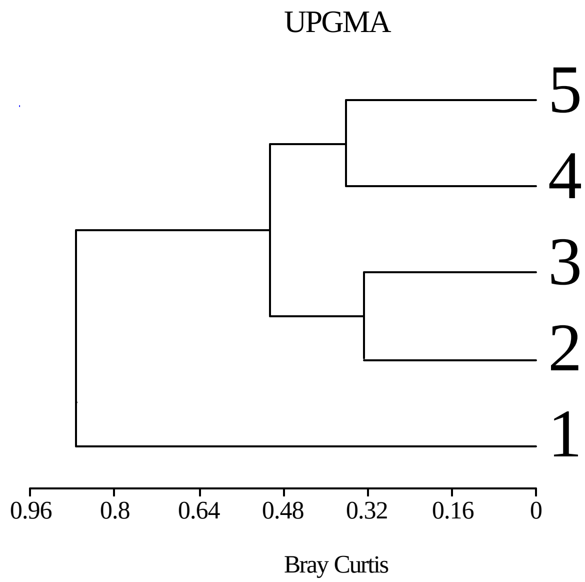


Figure 19. Genus Bray-Curtis dissimilarity of sampling sites on 4 September 2001.

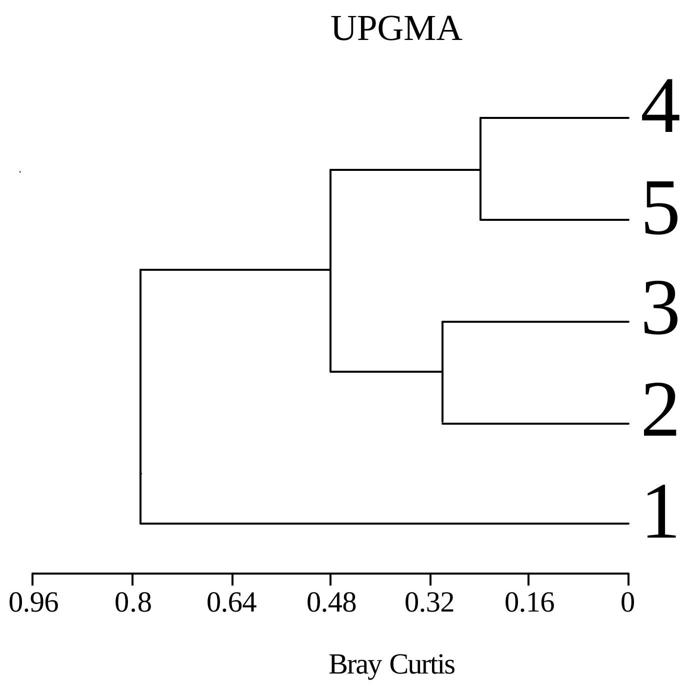


Figure 20. Genus Bray-Curtis dissimilarity of sampling sites on 18 September 2001.

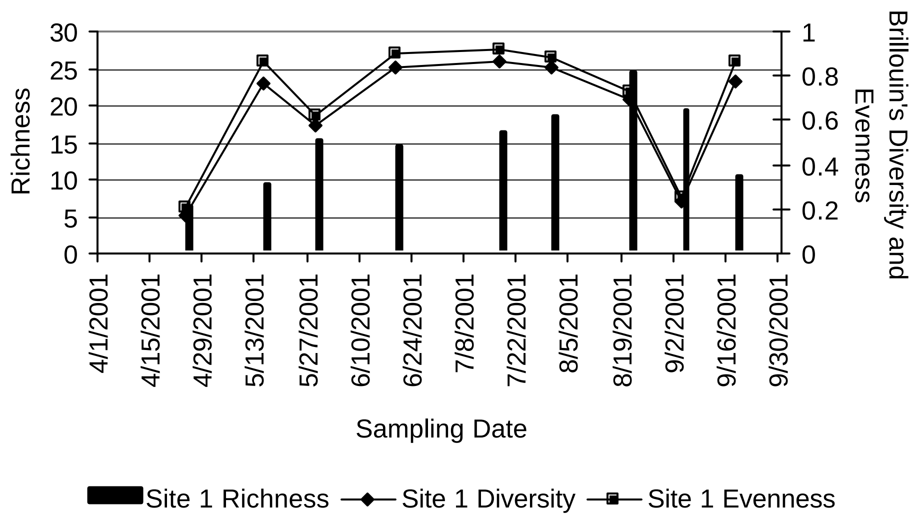


Figure 21. Brillouin's diversity, evenness and richness scores on each sampling date at Site 1, April through September 2001.

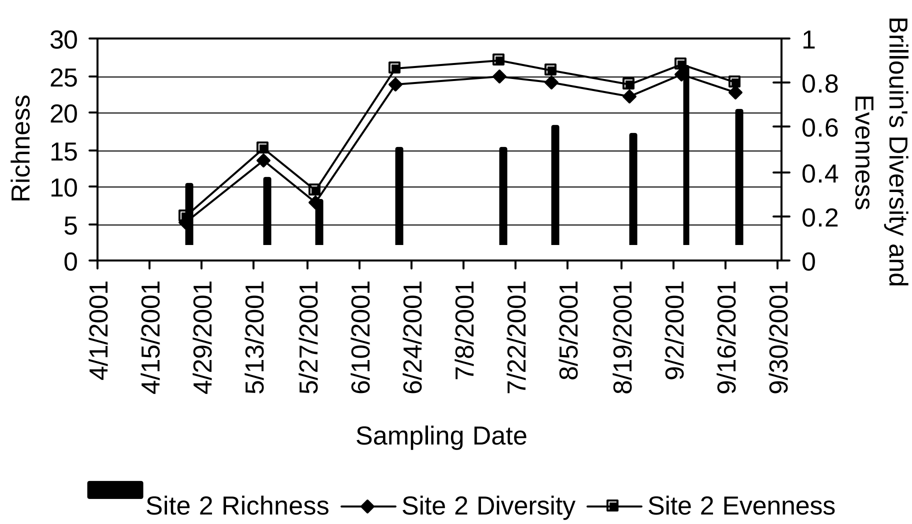


Figure 22. Brillouin's diversity, evenness and richness scores on each sampling date at Site 2, April through September 2001.

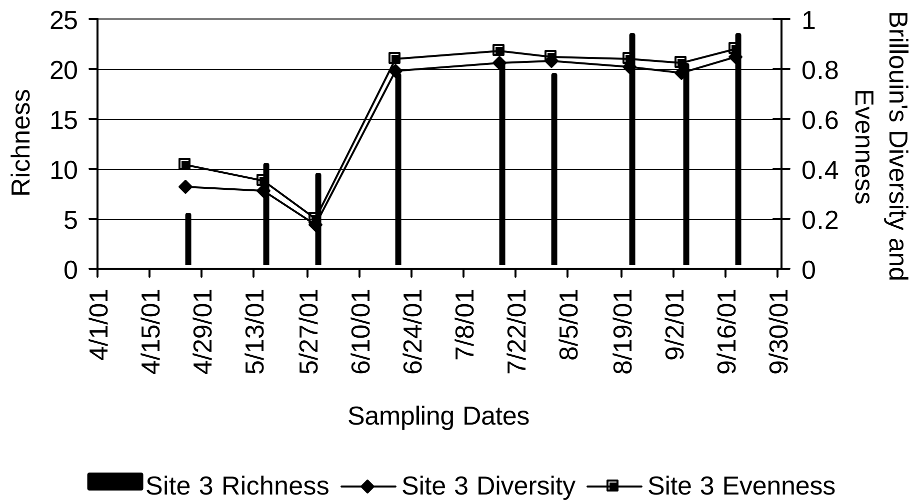


Figure 23. Brillouin's diversity, evenness, and richness scores on each sampling date at Site 3, April through September 2001.

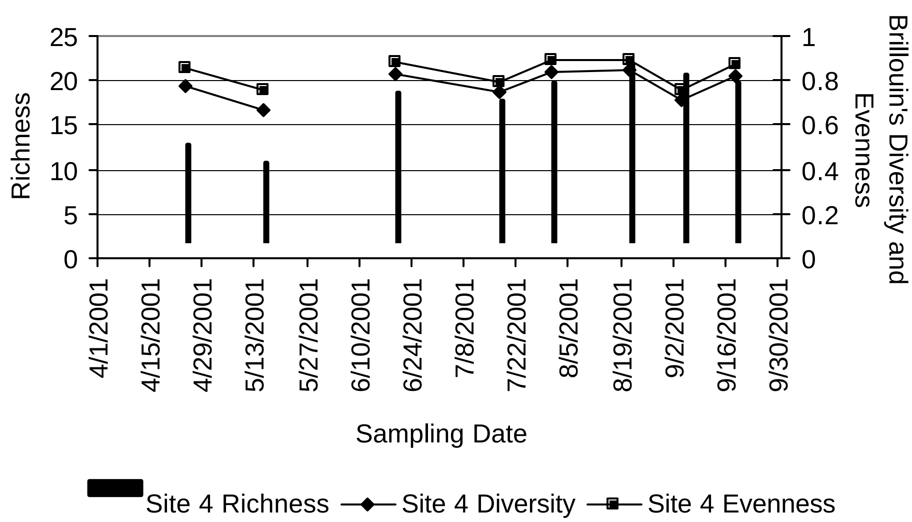


Figure 24. Brillouin's diversity, evenness, and richness scores on each sampling date at Site 4, April through September 2001.

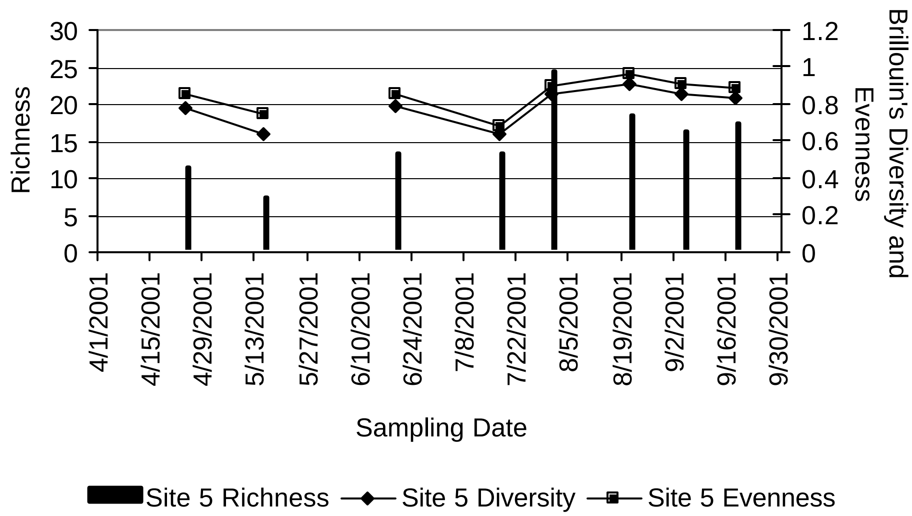


Figure 25. Brillouin's diversity, evenness, and richness scores on each sampling date at Site 5, April through September 2001.

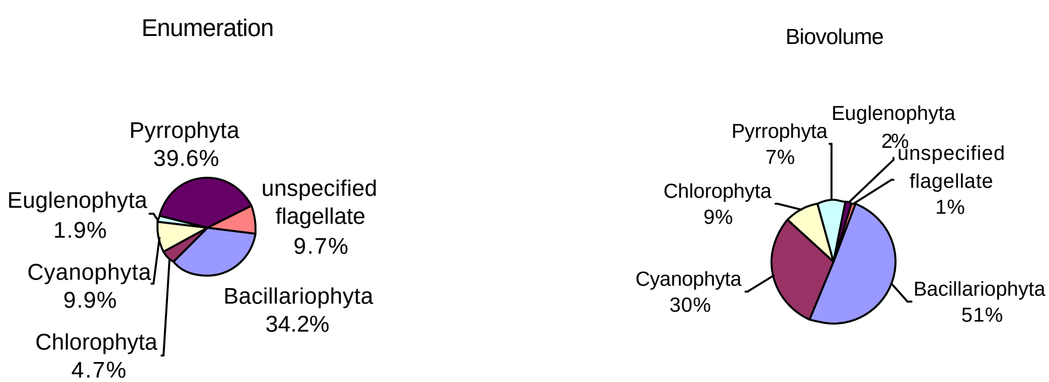


Figure 26. Percent contribution (density and volume) of each division to the phytoplankton assemblage in total count and biovolume from October 2000 through October 2001.

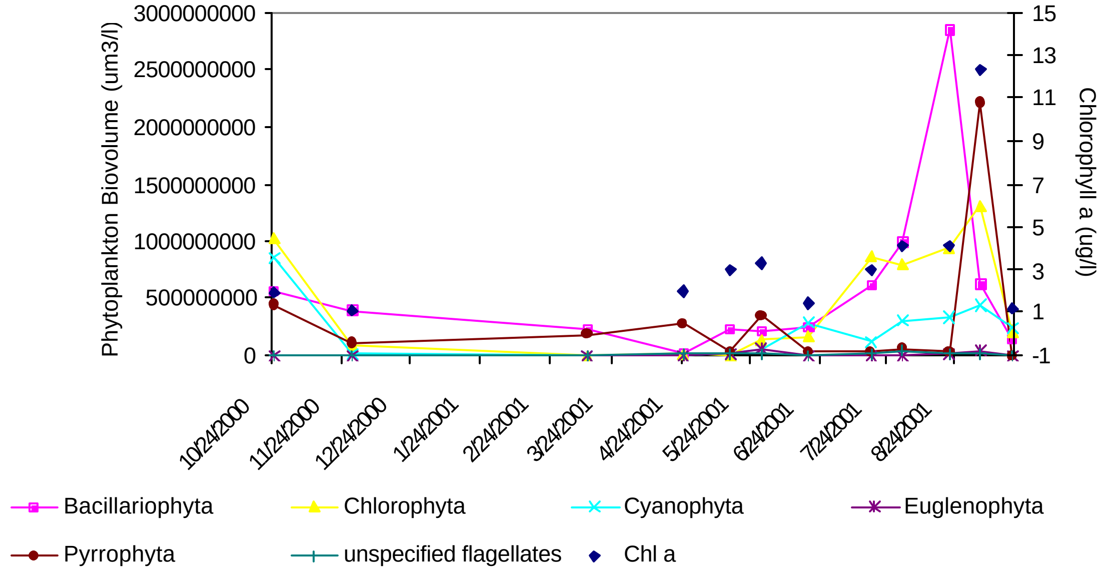


Figure 27. Biovolume of each Division and chlorophyll *a* concentration at Site 1 on each sampling date between October 2000 and October 2001.

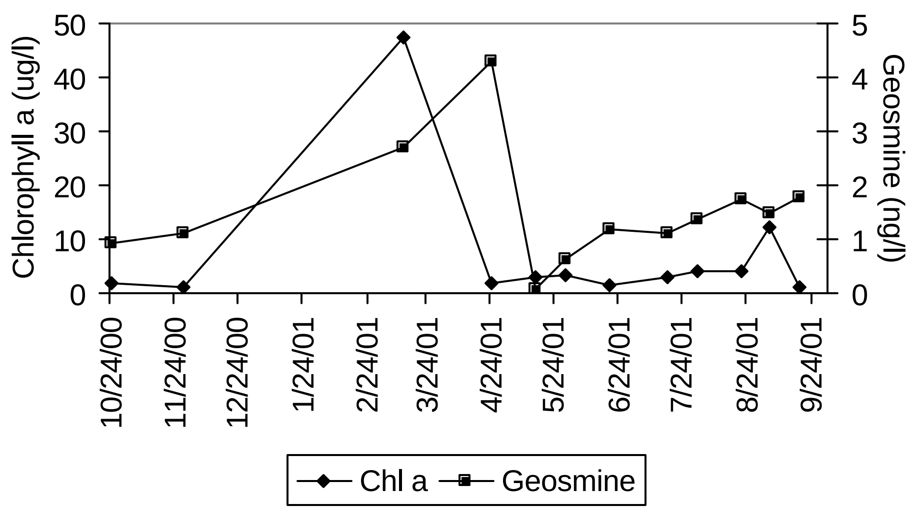


Figure 28. Chlorophyll *a* (Site 1) and geosmin concentrations (outlet of 66" water line from Oologah Lake) on each sampling date between October 2000 and October 2001.

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